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13. ABSTRACT (Maximum 200 words) This DURIP grant funded the capital equipment for a project to design and build a low-temperature, high magnetic field, near-field scanning optical microscope for the purpose of characterizing semiconductor nanostructures. All of the equipment necessary to build and operate this microscope has been purchased. The microscope has been completely designed, machined, and assembled. The need for robust, low-temperature, inertial motion has motivated us to invent a new kind of inertial motion motor. A prototype motor has been produced and is robust enough (i.e. drive voltage less than 5 V at room temperature) for low temperature operation. The 15/17 T superconducting magnet and cryogenic housing has been delivered and the facility to support this system is complete. We expect Oxford instruments to perform a final installation during the month of August.				
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**Low Temperature Near-Field Scanning Optical Microscope for Characterization of Semiconductor
Microstructures**

Final Report

Dr. Robert Grober

August 19, 1996

Army Research Office

Grant # DAAH04-95-1-0389

Yale University

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FINAL REPORT

1. Introduction:

This is a final report for DURIP funding (grant # DAAH04-95-1-0389) of a project to design, fabricate, and implement a low temperature, high magnetic field, near-field scanning optical microscope. Continuing support for the personnel associated with this project is supplied through ARO YIP grant # DAAH04-05-1-0368. The DURIP grant began in July 1995 and lasted one year.

All of the equipment necessary to operate this microscope has been purchased. A detailed list of the purchased equipment is provided in Appendix I. The microscope has been completely designed, machined, and assembled. The need to use low-temperature inertial motion has required us to invent a new kind of inertial motion motor. A prototype motor has been produced and is robust enough (i.e. drive voltage less than 5 V at room temperature) for low temperature operation. The 15/17 T superconducting magnet and cryogenic housing has been delivered and the facility to support this system is complete. We expect Oxford instruments to perform a final installation during the month of August and to then begin testing the system at low temperatures.

2. List of Appendixes:

Appendix 1 is a detailed list of all equipment purchased under this grant.

3. Report:

A. Statement of the Problem Studied:

The object of this project is to develop an instrument capable of performing high spatial resolution optical spectroscopy on semiconductor nanostructures at cryogenic temperatures ($T \geq 1.5$ K) and in extremely large magnetic fields ($B \leq 17$ T). To this end, we have designed and fabricated a low-temperature Near-Field Scanning Optical Microscope (NSOM). The microscope fits into a 1.4" diameter sample space which makes it compatible with 2" bore magnets. Novel sub-systems include an inertial motion motor, *in situ* focus mechanisms, optical access via fiber optics, and all electrical shear-force feedback.

B. Summary of Scientific Progress and Accomplishments:

We purchased a cryogenic magnet system from Oxford Instruments after considering competitive bids from Janis, American Magnetics, and Cyromagnetics. This system will allow experiments to temperatures as low as 1.3 K and magnetic fields as large as 17T. The magnet is designed with compensation coils, making it compatible with an existing dilution refrigerator should lower temperatures be required. The magnet system has been delivered and the facility to support the magnet is complete. It is expected that Oxford Instruments will make a final installation in August 1996.

All machined parts in the microscope are made of titanium. There are two major reasons for this material choice: 1) it is non-magnetic and 2) its expansion coefficient is reasonably well matched to PZT ceramics.

Porting optics in and out of the cryostat is done completely with fiber optics. The system is designed to work as a near-field microscope in both transmission and reflection geometries. The transmission optics are as follows. A near-field fiber probe (i.e. very small optical aperture) is maintained a few tens of nanometers above one side of the sample using all electrical shear force feedback. The other side of the sample is imaged onto a spatially coherent fiber bundle via *in situ* optics. This allows both collection mode and illumination mode near-field optical measurements in the transmission geometry. The reflection mode optics are as follows. The fiber bundle is imaged onto the surface of the

sample through a solid immersion lens. This bundle allows for both illumination and collection of optical signals. The sapphire solid immersion lens was obtained from Bruce Terris of IBM and will allow for imaging with a numerical aperture of order 1.8.

Macroscopic motion in the 1.4 inch diameter sample space is implemented via concentric cylinders that move relative to one another on linear bearings. The motion is controlled using inertial motion motors, invented by the researchers during the course of this grant. The advantage of these motors is that they are very robust, operating at room temperature with drive voltages as low as 5V. This system provides *in situ* focus for all of the collection optics and for the course approach of the near-field probe.

In addition to the microscope and magnet, we have developed an infrastructure of spectroscopic and scanned probe equipment that will support the microscope. The spectroscopic equipment includes an Argon ion pumped, tunable Ti:Sapphire laser, a 0.5 meter triple monochromator, and a liquid nitrogen cooled CCD detector. All scanned probe electronics and software are designed and built in our group. All laboratory equipment and scan electronics are controlled via National Instruments Labview software.

C. Publications and Manuscripts:

No manuscripts have yet resulted from this grant. We anticipate submitting an extensive manuscript to Review or Scientific Instruments once we have demonstrated low temperature operation.

D. Scientific Personnel:

This grant only supports capital equipment. The personnel working on the project are supported by ARO YIP grant # DAAH04-05-1-0368. They are Qiang Wu, a physics graduate student, and Robert Grober, the PI.

4. Report of Inventions:

We believe that the inertial motion motors we have developed are completely new and worthy of patent consideration. However, we have not yet proceeded with any intellectual property action.

5. Appendix 1: Summary of Equipment Purchases					
Date	Purchase Order	Company	Funding Source	Amount	Description
Helium Cryostat and Magnet					
12/7/95	PA67822RB	Oxford Instruments	Army	95,453.90	15/17 teslatron cryogenic magnet
12/7/95	PA67822RB	Beaver Transportation	Army	153.19	magnet delivery
4/4/96	PA64453RE	Oxford Instruments	Army	2,224.42	magnet installation
4/4/96	PA64453RE	Oxford Instruments	Yale	1,275.58	magnet installation
5/21/96	QO66713	Grainger	Yale	33.28	heavy duty electrical cords
6/6/96	ER306561	Home Depot	Yale	136.36	misc. hardware for cryostat mount
6/27/96	PCB60626	Home Depot	Yale	53.94	misc. hardware for cryostat mount
7/8/96	PA69718RF	Grainger	Yale	1,024.97	Dayton 3Z370 1/2 ton hoist
			subtotal	100,355.64	
Vacuum Pump for Cryostat					
4/8/96	PA64455RE	Hovac	Yale	8,708.14	60-E Turbo Pump and fittings
7/2/96	QO66796	Elm City Plumbing	Yale	62.71	misc. plumbing parts
7/22/96	QO66829	Televac	Yale	108.00	Thermocouple Vacuum Gauge
7/22/96	QO66828	orwalk Valve and Fittin	Yale	104.00	misc. plumbing parts
7/23/96	PA65744RE	Edwards High Vacuum	Yale	937.45	vacuum gauges and hoses
7/23/96	PA28557UE	HPS	Yale	403.30	misc. vacuum connectors
7/24/96	QO68915	Elm City Plumbing	Yale	45.21	misc. plumbing parts
			subtotal	10,368.81	
Vibration Isolation Legs					
4/17/96	PA68338RB	TMC	Yale	4,104.00	Non-Mag. Vibration Isolation Legs
			subtotal	4,104.00	
Machine Shop Services					
9/20/95	PA67404RB	EDERN	Army	10,741.00	machining of the microscope
			subtotal	10,741.00	
Misc. Mechanical Motion Components					
9/26/95	QO57754	Small Parts Inc.	Army	21.33	thin metal sheets
9/28/95	PA67463PB	Schneeberger	Army	660.88	linear bearings
10/5/95	QO58624	Sapphire Engineering	Army	202.81	1.5mm OD sapphire balls
10/25/95	PA67606RB	American Piezo	Army	2,625.30	piezoelectric ceramics
12/31/95	QO57756	United Titanium	Yale	258.85	titanium stock
12/31/95	QO58669	United Titanium	Yale	261.70	titanium screws
3/31/96	QO61423	Lake Shore Cryotronics	Yale	176.00	stycast 2850-FT epoxy
3/31/96	QO61396	McMaster	Yale	54.74	assorted solder flux
4/9/96	QO64810	Johnson Matthey	Yale	59.65	moly disulfide
4/19/96	ER271916	EDO Corp.	Yale	287.00	E100P piezo electric stack
4/25/96	QO64830	Johnson Matthey	Yale	59.37	titanium stock
6/4/96	QO66738	Thorlabs	Yale	79.00	piezo electric stack actuator
6/19/96	QO66788	Tico Titanium	Yale	104.83	titanium stock
			subtotal	4,956.29	

